

ON THE CONTRIBUTION OF "FRESH" COSMIC RAYS TO THE EXCESSES OF SECONDARY PARTICLES

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ABSTRACT

The standard model of cosmic ray propagation has been very successful in explaining all kinds of the Galactic cosmic ray spectra. However, high precision measurement recently revealed the appreciable discrepancy between data and model expectation, from spectrum observations of γ -rays, e^+/e^- and probably the B/C ratio starting from ~ 10 GeV energy. In this work, we propose that the fresh cosmic rays, which are supplied by the young accelerators and detained by local magnetic field, can contribute additional secondary particles interacting with local materials. As this early cosmic ray has a hard spectrum, the model calculation results in a two-component γ -ray spectrum, which agree very well with the observation. Simultaneously, the expected neutrino number from the galactic plane could contribute $\sim 60\%$ of IceCube observation neutrino number below a few hundreds of TeV. The same pp-collision process can account for a significant amount of the positron excesses. Under this model, it is expected that the excesses in \bar{p}/p and B/C ratio will show up when energy is above ~ 10 GeV. We look forward that the model will be tested in the near future by new observations from AMS02, IceCube, AS γ , HAWC and future experiments such as LHAASO, HiSCORE and CTA.

1. INTRODUCTION

Recent decade has witnessed the great progress made in Cosmic Ray (CR) physics. With new generation of space borne and ground based experiments, CRs are stepping into an era of high precision. PAMELA discovered a clear positron excess for energy between 10-100 GeV in 2009 (Adriani et al. 2009a). Recently, the AMS2 collaboration has released its first result, i.e. the positron fraction $e^+/(e^- + e^+)$ measurement with energy between ~ 0.5 GeV to ~ 350 GeV (Aguilar et al. 2013), which confirmed PAMELA positron excess with unprecedented high precision. These results have stimulated a lot of theoretical studies with point of view from either exotic process (Bergström et al. 2008; Barger et al. 2009; Yin et al. 2009; Zhang et al. 2009) or astrophysics process (Yüksel et al. 2009; Hooper et al. 2009; Hu et al. 2009; Blasi 2009).

Due to the fact that anti-proton excess has not been observed, the contribution to the e^+ excess from the interaction between CRs and InterStellar Medium (ISM) was generally regarded as unlikely and ignorable (Adriani et al. 2009b; Blasi & Serpico 2009; Mertsch & Sarkar 2009). Later on, high precision observation of diffuse γ -rays obtained by Fermi-LAT shows that the discrepancy between data and model prediction above ~ 10 GeV is evident (Ackermann et al. 2012a). Fermi-LAT excess actually is consistent with the multi-TeV excess observed by MILAGRO in inner galactic plane (Abdo et al. 2008) by taking into account the contribution from fresh CRs (Völk & Berezhko 2013). The diffuse γ -ray in CYGNUS region within tens of degrees observed by Fermi-LAT and MILAGRO (Ackermann et al. 2012b) was also explainable by fresh CRs (Bi et al. 2009). The continued excess all over the galactic plane and no excess outside the galactic plane does not favour the dark matter interpretation. Considering the fast energy loss, the IC scattering process of electron is constrained by earlier study (Atoyan et al. 1995). In short, the diffuse γ -ray excess tends to suggest

the existence of the extra CRs, which interact with the ISM.

The neutrino could only be generated from the interaction between CRs and ISM, which make it a unique probe to study the origin and acceleration of CRs. Thanks to the IceCube experiment, the very high energy neutrino observation has made great progress. The IceCube collaboration reported the detections of two PeV neutrino events and 26 other neutrino events from 30 to 400 TeV with 2-year data (Aartsen et al. 2013; IceCube Collaboration 2013). The number of events exceeds the background by 2.8σ and 3.3σ respectively. Recently updated result with a total number of 37 neutrino events from 30 TeV to 2 PeV corresponding to 5.7σ has been published for 3-year data combined (Aartsen et al. 2014b). By including the TeV energy neutrinos, the spectrum can be described by a power law with an index of -2.46. Two types of origins have been discussed in literatures: galactic and extra-galactic sources. As the extra-galactic contribution might be low to explain the IceCube observation (Abdo et al. 2010; The Fermi LAT collaboration et al. 2014; Neronov & Semikoz 2014). A lot of works focus on the galactic origins, which include the TeV γ -ray point sources (Fox et al. 2013; Neronov et al. 2014), the Galactic center, Fermi bubble region (Razzaque 2013; Ahlers & Murase 2014; Su et al. 2010) and the diffuse CR interaction with the ISM (Gupta 2013; Joshi et al. 2014; Guo et al. 2014). Most recently, Neronov A. and Semikoz D. find that both diffuse γ -ray and IceCube neutrino excesses can be well described if the spectrum index of galactic CRs is -2.5 (Neronov & Semikoz 2014). As the fresh CRs bear a harder spectrum than the one required in (Neronov & Semikoz 2014), its contribution to the IceCube neutrino excesses may not be ignorable.

With all of these high precision results, one can estimate the energy power of the excess particles. For simplicity, we assume that the diffuse γ -rays are all emitted in a distance of 8 kpc from solar system. According to

the integrated flux of diffuse γ -ray above 10 GeV, which is $2.5 \times 10^{-9} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ (Neronov & Semikoz 2014), the power of excess γ -ray is $\sim 2 \times 10^{37} \text{ ergs/s}^{-1}$. Similarly, the power of neutrino excess is estimated to be $\sim 10^{37} \text{ ergs}$ by adopting IceCube spectra mentioned above and extrapolate the lower energy side to 10 GeV (Aartsen et al. 2014a; Neronov & Semikoz 2014). The power of positron excess need to be estimated in a different way. Based on the excess positron flux measured by AMS02, its local energy density is $\sim 10^{-5} \text{ eV}$. Assuming this is the average value in the galaxy and considering the volume of our galaxy is $\pi(20 \text{ kpc})^2(0.2 \text{ kpc}) \sim 10^{67} \text{ cm}^3$, the power of excess positron is estimated to be $\sim 4 \times 10^{36} \text{ ergs/s}$ if the positron has a lifetime of 10^6 years. It is interesting to notice that the energy power of three excess particles is in the same order of magnitude and thus natural to ask whether these excesses of γ -rays, neutrinos and positrons share the same origin. If the answer is true, one possible explanation is that one of the hadronic interaction process is missed in the standard model of CR propagation. Following this picture and considering that all excess phenomena happens between ~ 10 GeV to sub-PeV, the CRs involved must have a hard spectrum between ~ 10 GeV to $\sim \text{PeV}$. In addition, the CRs should be efficient in interacting with interstellar medium. Such hard component of CRs and environment do exist in the galactic disk around the young accelerators. Traditionally, only the steady state CRs are considered when calculating the diffuse γ -ray, neutrino and e^+ . However the steady state solution can not describe the CRs under acceleration and the "fresh" CRs detained by magnetic field around the sources. It is understandable that the magnetic field near the source is stronger than the average one, which makes it difficult for the CRs to escape. This paper tends to study the contribution of the fresh CRs to secondary particle production.

The paper is organized in the following way. Section 2 describes the conventional propagation model of CRs and the additional secondary production from the fresh CRs interaction with ISM. Section 3 presents the results of the calculation compared with the observation. And finally, Section 4 gives the discussion and conclusion.

2. CR PROPAGATION AND INTERACTIONS IN THE GALAXY

The expanding diffusive shock, generated in the active phase of astrophysical object such as SNRs (Bell 1978a,b; Blandford & Ostriker 1978), Galactic Center (Ptuskin & Khazan 1981; Said et al. 1981; Giler 1983; Guo et al. 2013), can accelerate the CRs to very high energy. Then these particles would diffuse away from the acceleration site, and travel in the galaxy for $\sim 10^7$ years. During the journey, the impacts due to the fragmentation and radioactive decay in the ISM results in the production of secondary particles. In the meanwhile, the electron suffers energy loss in the interstellar radiation field (ISRF) and magnetic field, which may lead to the diffuse γ -ray emission. Those secondary particles would be a good tracer to understand the CR origin and propagation. Considering those effects, the propagation equation

can be written as:

$$\begin{aligned} \frac{\partial \psi(\vec{r}, p, t)}{\partial t} = & q(\vec{r}, p, t) + \vec{\nabla} \cdot (D_{xx} \vec{\nabla} \psi - \vec{V}_c \psi) \\ & + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi - \frac{\partial}{\partial p} \left[\dot{p} \psi - \frac{p}{3} (\vec{\nabla} \cdot \vec{V}_c \psi) \right] \\ & - \frac{\psi}{\tau_f} - \frac{\psi}{\tau_r} \end{aligned} \quad (1)$$

where $\psi(\vec{r}, p, t)$ is the density of CR particles per unit momentum p at position \vec{r} , $q(\vec{r}, p, r)$ is the source distribution, D_{xx} is the spatial diffusion coefficient, \vec{V}_c is the convection velocity, D_{pp} is the diffusion coefficient in momentum space and used to describe the reacceleration process, $\dot{p} \equiv dp/dt$ is momentum loss rate, τ_f and τ_r are the characteristic time scales for fragmentation and radioactive decay respectively. The spatial diffusion coefficient is assumed to be space-independent and has a power law form $D_{xx} = \beta D_0 (\rho/\rho_0)^\delta$ of the rigidity ρ , where δ reflects the property of the ISM turbulence. The reacceleration can be described by the diffusion in momentum space and the momentum diffusion coefficient D_{pp} is coupled with the spatial diffusion coefficient D_{xx} as (Seo & Ptuskin 1994)

$$D_{pp} D_{xx} = \frac{4p^2 v_A^2}{3\delta(4-\delta^2)(4-\delta)w} \quad (2)$$

here v_A is the Alfvén speed, w is the ratio of magnetohydrodynamic wave energy density to the magnetic field energy density, which can be fixed to 1. The CRs propagate in an extended halo with a characteristic height z_h , beyond which free escape of CRs is assumed. The values of the key parameters of CR propagation are listed in Table 1, which is similar with previous studies except the tuned injection spectrum (Yin et al. 2009; Zhang et al. 2010; Yuan et al. 2015).

TABLE 1
THE PROPAGATION PARAMETERS

$D^0 (10^{28} \text{ cm}^2 \text{ s}^{-1})$	5.5	$\rho_0 \text{ (GV)}$	4
δ	0.45	$v_A \text{ (km s}^{-1}\text{)}$	32
$R_{max} \text{ (kpc)}$	20	$z_h \text{ (kpc)}$	4

It is generally believed that SNRs are the sources of Galactic CRs. The spatial distribution of SNRs is usually described by following empirical formula:

$$f(r, z) = \left(\frac{r}{r_\odot} \right)^a \exp \left(-b \cdot \frac{r - r_\odot}{r_\odot} \right) \exp \left(-\frac{|z|}{z_s} \right), \quad (3)$$

where $r_\odot = 8.5 \text{ kpc}$ is the distance from the Sun to the Galactic center, $z_s \approx 0.2 \text{ kpc}$ is the characteristic height of Galactic disk, $a=1.25$ and $b=3.56$ are adopted from (Trotta et al. 2011), which are suggested from Fermi studies on diffuse γ -ray emission in the 2nd Galactic quadrant (Tibaldo et al. 2009). The accelerated spectrum of primary CRs at source region is assumed to be a broken power law function:

$$q(p) = q_0 \times \begin{cases} (p/p_{br})^{-\nu_1} & \text{if } (p < p_{br}), \\ (p/p_{br})^{-\nu_2} \cdot f(\hat{p}) & \text{if } (p \geq p_{br}) \end{cases} \quad (4)$$

where p is the rigidity, q_0 is the normalization factor for all nuclei, relative abundance of each nuclei follows

the default value in GALPROP package. p_{br} is the broken energy and ν_1, ν_2 is the spectrum index before and after the broken energy p_{br} . $f(\hat{p})$ is used to describe the high energy cut-off. For the primary electron, a soft spectrum index with the value of -3.5 at the rigidity 2 TV is adopted in order to agree with HESS observation (Aharonian et al. 2008). For the nuclei, to reproduce the knee structure of CRs, $f(\hat{p})$ can be described as following formula based on Hörandel model (Hörandel 2004):

$$f(p_{knee}) = \left[1 + \left(\frac{p}{\hat{p}} \right)^{\epsilon_c} \right]^{\frac{-\Delta\gamma}{\epsilon_c}} \quad (5)$$

where $\Delta\gamma$ and ϵ_c characterize the change in the spectrum at the break rigidity \hat{p} . Detailed information of the parameters is listed in Table 2.

TABLE 2
THE INJECT SPECTRUM OF PRIMARY CRs

parameters	Nuclei	Electron
$\log(q_0)$	-8.31	-9.367
ν_1	1.92	1.5
ν_2	2.31	2.7
$p_{br}(GV)$	9	5.7
$\hat{p}(PV)$	3.68	
$\Delta\gamma$	0.44	
ϵ_c	1.84	

The ISM account for about 10%-15% of the total mass in the Galactic disk and its chemical composition is dominated by hydrogen and helium. The helium fraction is 11% by number density. The hydrogen gas n_H includes three main components in molecular (H_2), atomic (H_I) and ionized (H_{II}) states. The default gas distribution in GALPROP is adopted in our calculation, which is based on the survey results and related modeling (Bronfman et al. 1988; Gordon & Burton 1976; Cordes et al. 1991).

By using publicly available numerical code GALPROP and taking the main parameters described above, the directly measured proton spectrum up to ~ 100 TeV can be successfully reproduced as shown in Fig. 1. The solar modulation potential is assumed to 550 MV. Simultaneously, the calculation can provide all spectra of observable secondary particles for comparison with the experimental results. We will refer those results from corresponding calculation as convention model results hereafter.

Convention model calculation can describe well the high latitude diffuse γ -ray spectra but not enough for the spectra in the galactic plane (Ackermann et al. 2012a). Distributed along the galactic disk, the fresh CRs has been discussed and expected to resolve the deficit problem (Bi et al. 2009; Neronov & Semikoz 2014). If CRs do have instant acceleration and injection, the propagation of CRs does have a uniform diffusion parameters everywhere (inside and outside the galactic plane) and the CR sources do have continuous spatial and temporal distribution as assumed in GALPROP, then the solution of steady state can describe the integrated CR distribution, including fresh and old CRs. However, the processes of both CR acceleration and injection take time, and

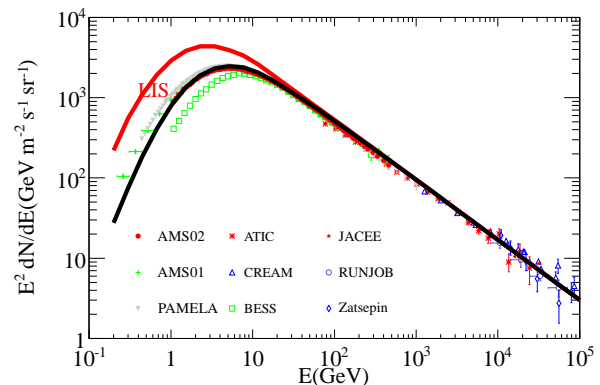


FIG. 1.— The proton spectrum in the convention model. The experiment data of proton come from: AMS02(Consolandi & on Behalf of the AMS-02 Collaboration 2014), ATIC(Panov et al. 2006), PAMELA(Adriani et al. 2011b), AMS01(Alcaraz et al. 2000b), CREAM(Ahn et al. 2010), BESS(Sanuki et al. 2000), JACEE(Asakimori et al. 1998), RUNJOB(Apanasenko et al. 2001), Zatsepin(Hörandel 2006)

CR should diffuse slower in the galactic plane than in the halo. The CRs should spend longer time in galactic disk and have effectively more interaction with ISM than what is calculated in GALPROP. Instead of using non-uniformly distributed diffusion coefficient in the calculation, we simply add a fresh CR component in the source region to take care of the generation of additional secondary particles. One should be reminded that the fresh CR component does not take part in the propagation as the primary or secondary particles. In this work, we assume that the fresh CRs have the same spatial distribution as that of the SNRs. Furthermore, the spectrum of the fresh CRs should be close to the injected spectrum of primary CRs. As a matter of fact, we simply employ the injected spectrum of primary CRs as in Formula 4, but with a rescaled normalization factor, which is determined by the detained time. For example, if the fresh CRs take twice the time to escape from galactic disk than that of a normal diffusion supposed by GALPROP calculation, the interaction between the fresh CRs and the ISM would be doubled and the rescaled normalization factor would be one. In this work, the rescaled normalization factor is a free parameter and determined by best accordance between the model calculation and the observation.

3. RESULTS ON SECONDARY PARTICLE SPECTRA

Base on above discussion, the secondary particles are produced from two components: steady state CRs in convention model and the fresh CRs. The secondary spectra from the contribution of convention model can be directly obtained from the GALPROP package calculation. The secondary particle production from the fresh CRs is calculated under the GALPROP frame by switching off the propagation of fresh CRs to keep the fresh CR spectrum unchanged and limit the related interactions only in the source region. After the production, the secondary particles follow the normal propagation as those from conventional model calculation. With which, the spectra of additional secondary particles can be obtained. Given a rescaled normalization factor, the summed spectra of secondary particles can be compared with the observa-

tion. By adjusting the rescaled normalization factor, we find that a value of 0.4 offer the best agreement.

3.1. Diffuse γ -ray emission

The diffuse γ -rays in the galactic plane are produced through three major processes: decay of π^0 generated by pp -collision, IC scattering off the ISRF and bremsstrahlung by electrons. In the case of IC calculation, the widely used ISRF model is adopted (Strong et al. 2000; Porter & Strong 2005).

According to the available spectra of high energy diffuse γ -ray on the galactic disk, four regions are studied in this work: (a) inner most galactic plane ($|b| < 5^\circ$ & $|l| < 30^\circ$), (b) inner galactic plane ($|b| < 8^\circ$ & $|l| < 80^\circ$), (c) outer galactic plane ($|b| < 8^\circ$ & $|l| > 80^\circ$) and (d) CYGNUS region. Fig. 2 (a)-(c) show the comparisons of the diffuse γ -rays from region (a)-(c). All of our convention model calculations agree well with those from Fermi-LAT collaboration (Ackermann et al. 2012a). The general conclusion is that model calculation can't describe the observation with the energy above a few GeV. After adding the contribution from fresh CRs, also dominated by π^0 decay, the agreements between model calculations and observations are much better improved from 1 to 100 GeV. The hard spectrum is expected to continue to very high energy due to the hard spectrum of the fresh CR contribution, which can be tested by diffuse γ -ray observation at higher energy. Fortunately, multi-TeV observation has been performed by ground-based EAS experiments in CYGNUS region. Fig. 2 (d1) show the spectrum observed by Fermi-LAT in a wide CYGNUS region together with model calculations. Though fresh CR helps to explain the observation above 10GeV, the overall theoretical spectrum underestimates the Fermi-LAT one. This is probably because that CYGNUS region is a star formation region which contains many accelerators, old and young. A full understanding should take into account all contributions, including these from point sources and extended sources. Another possibility is that the ISM in this region is not properly modeled in the calculation, if we increase the amount of gas by 25%, the calculation can have a perfect agreement with the observation. ARGO-YBJ performed TeV observation in a slightly different area in CYGNUS region as shown in Fig. 2 (d2). The calculated flux agrees with the observation within experimental error. However, the measured flux has a large uncertainty and precision test is clearly foreseen with new observation from Tibet-AS γ (Sako et al. 2009), HAWC (Abeysekara et al. 2013) and future experiments such as LHASSO (Cao 2010), HiSCORE (Tluczykont et al. 2012). Fig. 2 shows the spectra measurement by EGRET and MILAGRO from a narrow band of CYGNUS region along galactic plane. Model calculation shows very good agreement with the observation from sub-GeV to tens of TeV energy. The fresh CRs contribute almost all the γ -ray emission in multi-TeV energy. More accurate observations of diffuse γ -rays above multi-TeV energy will be crucial in testing the fresh CR hypothesis.

3.2. Diffuse neutrino emission

The charged pion decay will produce neutrinos accompanying with the γ -rays. Different from γ -ray observation,

neutrinos interact very weakly with matter and very large volume of target material is required to detect the neutrino events.

With a cubic kilometer ice telescope below the surface of the South Pole, the IceCube collaboration reported a detection of 37 neutrino candidate events from 30 TeV to 2 PeV with a backgrounds of 8.4 ± 4.2 from CR muon events and $6.6^{+5.9}_{-1.6}$ from atmospheric neutrinos during a livetime of 988 days (Aartsen et al. 2014b). By including TeV measurement, the neutrino spectrum is obtained from \sim TeV to \sim PeV energy (Aartsen et al. 2014a). The left panel of Fig. 3 shows the IceCube data points together with model calculation. It can be seen that the theoretical calculation of allsky flux in black solid line is lower than the experiment observation. The best-fitted result, shown in gray solid color, indicate that the fresh CRs contribute $\sim 60\%$ of IceCube observation. It should be noted that the galactic neutrino flux mainly come from galactic plane according to our model calculation as shown in the right panel of Fig. 3 in black solid line. This conclusion apparently contradict with that of IceCube collaboration, which claimed an isotropic distribution based on current limited number of neutrino events. To describe the isotropic neutrino distribution, extra-galactic contribution is necessary. In fact, the neutrino flux from extra-galaxy is constrained by the measurements of extra-galactic γ -ray background (EGB) (Abdo et al. 2010; The Fermi LAT collaboration et al. 2014) and expected to be at the level of 10%-50% contribution from star forming galaxies (Neronov & Semikoz 2014), which is consistent with the part uncovered by the fresh CRs.

Nevertheless, we can compare the number of neutrino calculation and observation as listed in Table 3. N_{theo} is calculated neutrino numbers in our model after considering the 15° angular resolution of IceCube. We first smear the neutrino distribution by 15° to obtain the expected observational distribution as shown by the red solid line in the right panel of Fig. 3. Then, we integrate the neutrino number distribution with latitude coordinate from -20° to 20° as indicated by the arrows in the right panel of Fig. 3 and get the N_{theo} . N_{bkg} is the background numbers, estimated by multiplying the number of event fraction in chosen region with the total background numbers ($8.4+6.6$) assuming an isotropic background distribution. N_{obs} is the neutrino numbers observed by IceCube experiments in the correspondent region. It is interesting to note that the summation of N_{theo} and N_{bkg} agree with N_{obs} very well for four regions in the galactic plane. The four regions have a same definition as that were used for comparison of diffuse γ -ray spectra in previous section, except the latitude interval is fixed to $|b| < 20^\circ$ to take into account the IceCube angular resolution.

3.3. The ratio of \bar{p}/p and B/C

There is a great astrophysical interest in CR antiprotons and Borons. It is believed that most of antiprotons and Borons are originated from collisions of CR with ISM. Therefore the information of CR propagation can be extracted from the comparison between the spectra of secondary particles with those of primary CRs. Base on the above discussion, the fresh CRs can explain the diffuse γ -ray excess, and part of the IceCube neutrinos. It

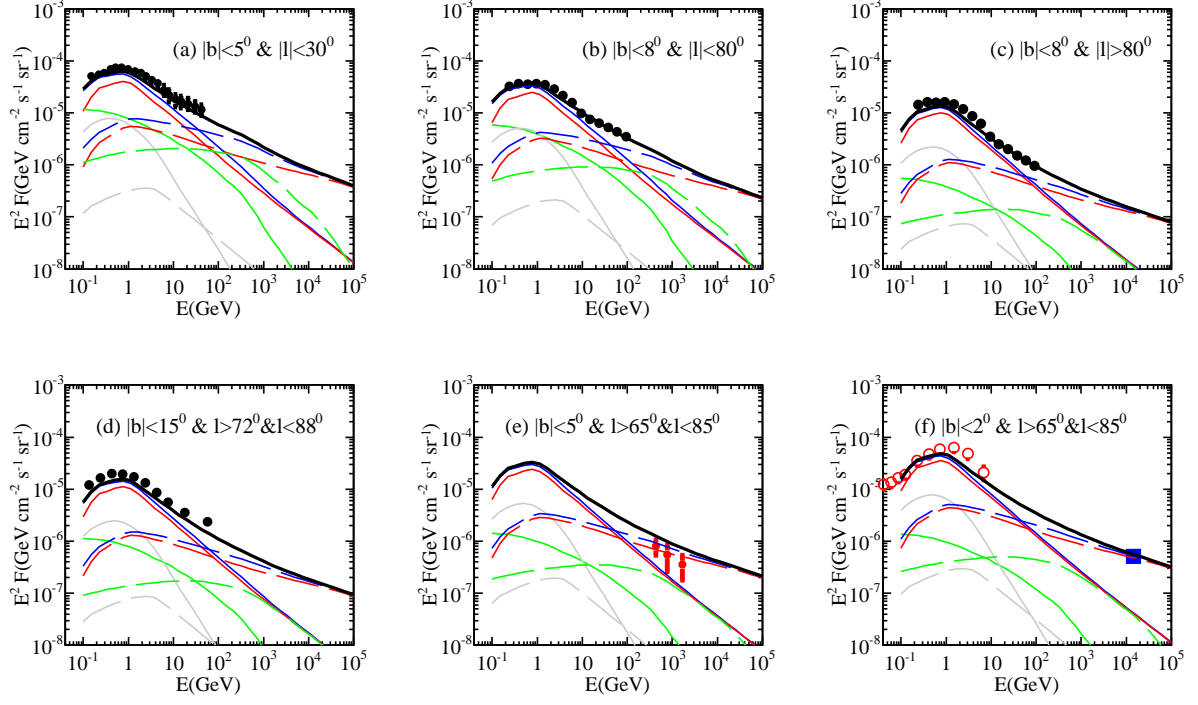


FIG. 2.— The calculated γ -ray spectrum: The red color shows the π^0 decay, green color shows the IC scattering, gray color shows the bremsstrahlung process and the black color shows the total one. The data at GeV energy range with black circle is from Fermi-LAT (Macias & Gordon 2014; Abdo et al. 2010; Ackermann et al. 2012a,b) and with red open circle is from EGRET (Hunter et al. 1997). The data at TeV energy range with red color points is from ARGO experiment (Sciascio 2014); The data at 15 TeV energy with blue quadrangle points is from MILAGRO experiment (Abdo et al. 2008)

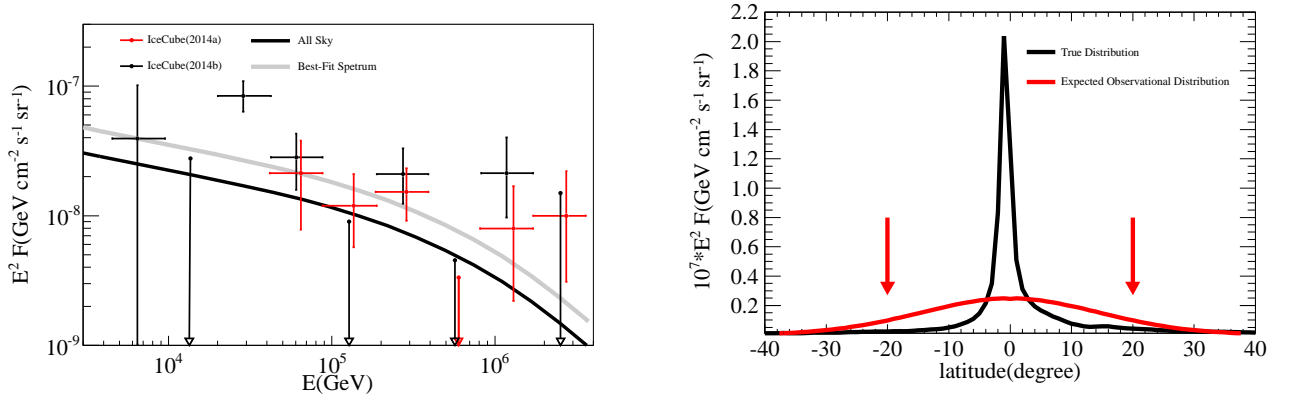


FIG. 3.— The calculated diffuse neutrino spectrum (left panel) from collision of the CRs with the ISM. The data is astrophysical neutrino observation (Aartsen et al. 2014b,a). The right panel is the integrated neutrino flux for $E > 30$ TeV along $l=0$. The black color is the true direction in our model and the red color is the reconstructed direction after considering the angle resolution of 15%.

is no doubt that the secondary particle antiproton and Boron should exhibit excesses for energy above tens of GeV correspondingly.

The left panel of Fig. 4 shows the calculated \bar{p}/p and the right panel shows the B/C . The blue and red dashed line presents the calculated results from conventional and fresh CR components respectively. The black solid line gives the total contribution. Considering the contribution of fresh CRs, the overall calculation on the ratio of \bar{p}/p is a little higher than PAMELA observation (Adriani et al. 2010, 2014a). However, the uncertainty of \bar{p} production cross section is $\sim 25\%$ over the energy range 0.1 - 100 GeV (Donato et al. 2001, 2009), which should

lead to a same level of uncertainty in the ratio calculation. Taking all of those factors into account, the model calculation is consistent with the observation within the errors. On the other hand, the ratio of B/C is quite consistent with AMS02 observation after considering the fresh CR contribution. Owing to its hard spectrum, the fresh CRs induced secondary \bar{p} and Boron inherit a similar hard spectrum, which make the ratio of $\bar{p}/p, B/C$ considerably flatter than that from conventional model. Such a tendency is not obvious in current observation. In the future, high statistic and TeV energy observation can offer a crucial and definitive identification of this model.

TABLE 3
THE COMPARISON BETWEEN THEORETICAL CALCULATION AND THE
OBSERVATION OF ICECUBE (AARTSEN ET AL. 2014B)

Region	N_{theo}	N_{bkg}	N_{obs}	Event Number
Inner most Galactic Plane	3.0	0.9	5	#2, #14, #22 #24, #25,
Inner Galactic Plane	6.4	2.4	10	#2, #4, #14, #22 #24, #25, #29, #33, #34, #35
Outer Galactic Plane	3.4	3	5	#13, #3, #6, #27, #5
Cygnus Region	0.6	0.4	2	#29, #34

3.4. Positron and Electron Excess

The charged pion decay will produce e^+e^- accompanying with the neutrino. In this section, the contribution of secondary particle e^+e^- from the fresh CRs interaction with ISM will be discussed.

The left panel of Fig. 5 shows the positron spectra from two contributions. The blue and red dash line stand for the convention model and fresh CR calculation. Because of the energy loss during the propagation of positron, the resulting spectrum of positron from fresh CRs become softer, which make the sum of the two contributions not enough to explain the positron excess as shown by the black dash line. The pulsar sources or exotic physical process is required to account for the discrepancy. According to the pulsar model (Yuan et al. 2015), positron spectrum from pulsar can be described by formula 4. Combined the three parts of components, the total calculation agree with AMS02 observation well as shown in black solid line.

The right panel of Fig. 5 contains the spectrum of electron from observations and calculations. The blue dash line is for the primary electron from the acceleration sources and the red dash line is the summation of three contributions as for case of positron. In total, they agree with the spectra measured by PAMELA and AMS02 as shown in black solid line.

Because of the good agreement between the model calculation and observation for both positron and electron spectra, without surprise our model describe very well the ratio of positron to electron as shown in Fig. 6.

4. DISCUSSION AND CONCLUSION

Origin, acceleration and propagation are the fundamental problems of CRs physics. In an era when high precision and multi-messenger observation results keep flood in, when various excesses and new phenomena continually pop up, the successful standard model of CRs is facing stringent test and refinement. Primary spectra are the most important inputs for the stand model

and have decisive effect to the spectra of secondary particles. While primary spectra measured by PAMELA and CREAM hint that galactic CRs may have a hard component at the source and can be responsible for the diffuse γ -ray and neutrino excesses. More accurate observation made by AMS02 apparently disapproves the rapid hardening of primary nucleus spectra around 200 GV rigidity. To recover the production of the hard spectra for diffuse γ -rays in galactic plane, an alternative solution is that the fresh CRs might have stayed longer in galactic disk than we previous have thought.

Instead of incorporating a spatial dependent diffusion coefficient in the calculation, by simply adding a fresh CR component to account for the additional secondary particles production, the diffuse γ -ray excess from 10 GeV to multi-TeV energy can be successfully explained. According to which, we found that the fresh CRs should spend about 40% longer time in galactic plane than that assumed by standard model. Same process can generate additional neutrino and explain about half of the Ice Cube neutrino flux. However, just like diffuse γ -rays, these diffuse neutrinos lie on the galactic plane and have a high level of anisotropic distribution. To fully understand the isotropic Ice Cube neutrino, extra-galactic contribution is inevitable. Though the fresh CRs can generate right amount of electron and positron, but they are not able to explain the total electron and positron excess simply because of the energy loss on the journey of propagation. If electron and positron can undergo a fast diffusion with less energy loss, we expect that fresh CRs can fully account for the excesses. In current scenario, electron and positron contribution from astrophysics sources, such as pulsar is necessary. A very important difference between pulsar and fresh CRs is that the latter model predicts additional production for all secondary particles, including anti-proton and Boron. According to our calculation, the ratio of \bar{p}/p and B/C will become flatter for energy above tens of GeV. High precision observation of flat ratios from AMS02 will be the smoking gun to test the fresh CR model. From theoretical point of view, a spatial dependent diffusion coefficient may lead to an observable hard component in primary CRs, further theoretical study is needed probably under the frame of DRAGON (Grygiel et al. 2008).

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REFERENCES

- Aartsen, M. G., Abbasi, R., Abdou, Y., et al. 2013, Physical Review Letters, 111, 021103
Aartsen, M. G., Ackermann, M., Adams, J., et al. 2014a, ArXiv e-prints, arXiv:1410.1749
—, 2014b, Physical Review Letters, 113, 101101
Abdo, A. A., Allen, B., Aune, T., et al. 2008, ApJ, 688, 1078
Abdo, A. A., Ackermann, M., Ajello, M., et al. 2010, Physical Review Letters, 104, 101101
Abeysekara, A. U., Alfaro, R., Alvarez, C., et al. 2013, Astroparticle Physics, 50, 26
Ackermann, M., Ajello, M., Atwood, W. B., et al. 2010, Phys. Rev. D, 82, 092004
—, 2012a, ApJ, 750, 3
Ackermann, M., Ajello, M., Allafort, A., et al. 2012b, A&A, 538, A71
Adriani, O., Barbarino, G. C., Bazilevskaya, G. A., et al. 2009a, Nature, 458, 607
—, 2009b, Physical Review Letters, 102, 051101
—, 2010, Physical Review Letters, 105, 121101
—, 2011a, Physical Review Letters, 106, 201101

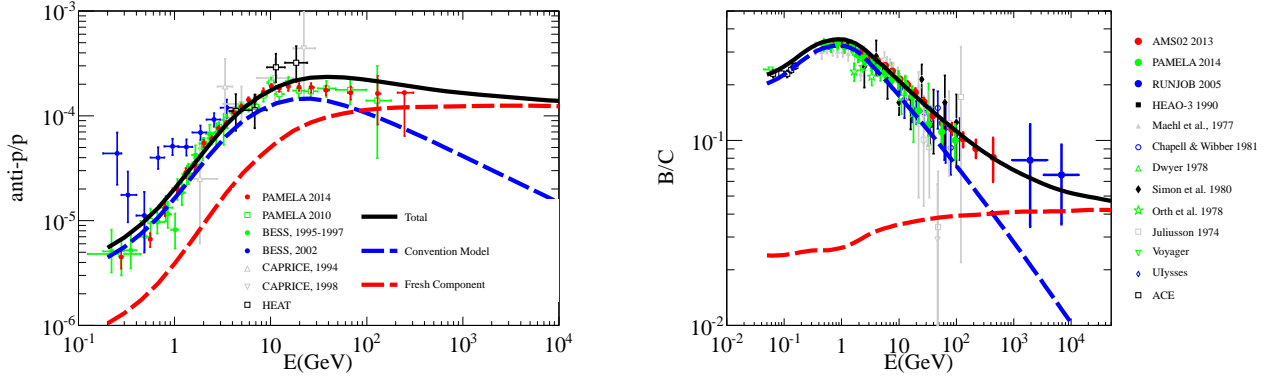


FIG. 4.— The calculated \bar{p}/p (left panel) and B/C (right panel). The \bar{p}/p data from: PAMELA 2014 (Adriani et al. 2014a), PAMELA 2010 (Adriani et al. 2010), BESS 1995-1997 (Orito et al. 2000), BESS 1999 (Asaoka et al. 2002), CAPRICE 1994 (Boezio et al. 1997), CAPRICE 1998 (Boezio et al. 2001), HEAT (Beach et al. 2001). The B/C data from: AMS02 (Aguilar 2013), PAMELA (Adriani et al. 2014b), RUNJOB (Derbina et al. 2005), Juliusson (Juliusson 1974), Dwyer (Dwyer 1978), Orth (Orth et al. 1978), Simon (Simon et al. 1980), HEAO-3 (Engelmann et al. 1990), Maehl (Maehl et al. 1977), Voyager (Lukasiak 1999), Ulysses (Duvernois et al. 1996), ACE (Davis et al. 2000) and for other references see (Stephens & Streitmatter 1998).

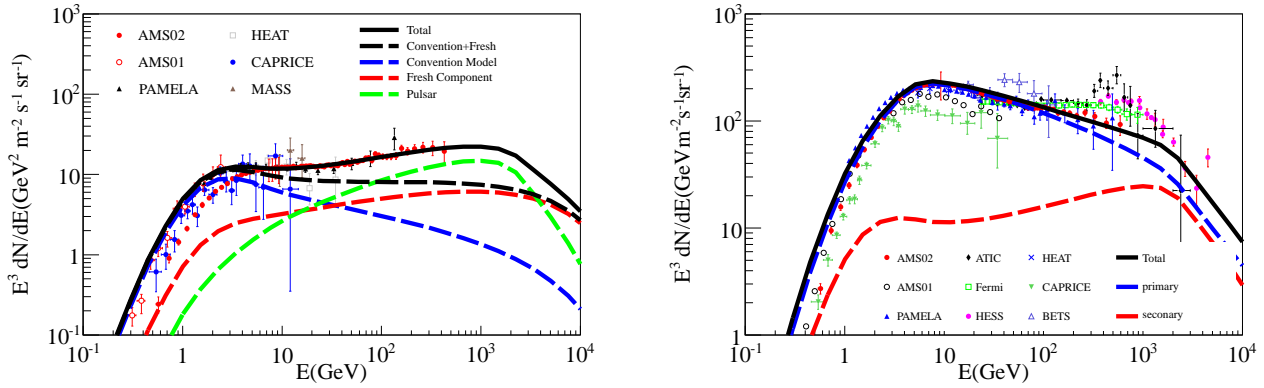


FIG. 5.— The calculated positron (left panel) and electron (right panel) spectrum. The experiment datas are adopted from AMS02 (Aguilar et al. 2014), AMS01 (Alcaraz et al. 2000a), PAMELA (Adriani et al. 2009a, 2011a), HEAT (Barwick et al. 1998), CAPRICE (Boezio et al. 2000), ATIC (Chang et al. 2008), Fermi-LAT (Ackermann et al. 2010), HESS (Aharonian et al. 2008) and BETS (Torii et al. 2001).

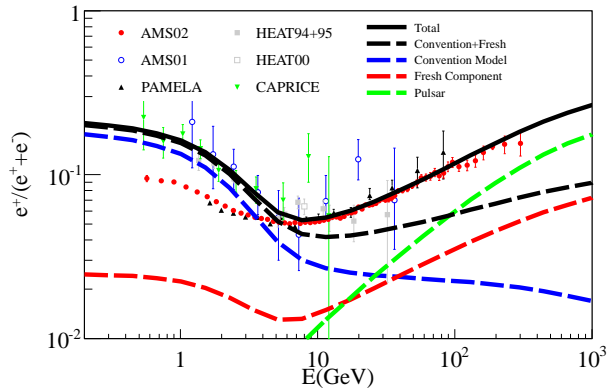


FIG. 6.— The calculated positron fraction. The experiment datas are adopted from AMS02 (Aguilar et al. 2013), AMS01 (AMS-01 Collaboration et al. 2007), PAMELA (Adriani et al. 2009a), HEAT94+95 (Barwick et al. 1997), HEAT00 (Coutu et al. 2001) and CAPRICE (Boezio et al. 2000).

—. 2011b, *Science*, 332, 69
 —. 2014a, *Physics Reports*, 544, 323
 —. 2014b, *ApJ*, 791, 93
 Aguilar, M. 2013, *CERN Courier*, 53, 8,22
 Aguilar, M., Alberti, G., Alpat, B., et al. 2013, *Physical Review Letters*, 110, 141102

Aguilar, M., Aisa, D., Alvino, A., et al. 2014, *Physical Review Letters*, 113, 121102
 Aharonian, F., Akhperjanian, A. G., Barres de Almeida, U., et al. 2008, *Physical Review Letters*, 101, 261104
 Ahlers, M., & Murase, K. 2014, *Phys. Rev. D*, 90, 023010
 Ahn, H. S., Allison, P., Bagliesi, M. G., et al. 2010, *ApJ*, 714, L89
 Alcaraz, J., Alpat, B., Ambrosi, G., et al. 2000a, *Physics Letters B*, 484, 10
 Alcaraz, J., Alvisi, D., Alpat, B., et al. 2000b, *Physics Letters B*, 472, 215
 AMS-01 Collaboration, Aguilar, M., Alcaraz, J., et al. 2007, *Physics Letters B*, 646, 145
 Apanasenko, A. V., Sukhadolskaya, V. A., Derbina, V. A., et al. 2001, *Astroparticle Physics*, 16, 13
 Asakimori, K., Burnett, T. H., Cherry, M. L., et al. 1998, *ApJ*, 502, 278
 Asaoka, Y., Shikaze, Y., Abe, K., et al. 2002, *Physical Review Letters*, 88, 051101
 Atoyan, A. M., Aharonian, F. A., & Völk, H. J. 1995, *Phys. Rev. D*, 52, 3265
 Barger, V., Keung, W.-Y., Marfatia, D., & Shaughnessy, G. 2009, *Physics Letters B*, 672, 141
 Barwick, S. W., Beatty, J. J., Bhattacharyya, A., et al. 1997, *ApJ*, 482, L191
 Barwick, S. W., Beatty, J. J., Bower, C. R., et al. 1998, *ApJ*, 498, 779
 Beach, A. S., Beatty, J. J., Bhattacharyya, A., et al. 2001, *Physical Review Letters*, 87, 271101
 Bell, A. R. 1978a, *MNRAS*, 182, 147
 —. 1978b, *MNRAS*, 182, 443
 Bergström, L., Bringmann, T., & Edsjö, J. 2008, *Phys. Rev. D*, 78, 103520
 Bi, X.-J., Chen, T.-L., Wang, Y., & Yuan, Q. 2009, *ApJ*, 695, 883

- Blandford, R. D., & Ostriker, J. P. 1978, *ApJ*, 221, L29
- Blasi, P. 2009, *Physical Review Letters*, 103, 051104
- Blasi, P., & Serpico, P. D. 2009, *Physical Review Letters*, 103, 081103
- Boezio, M., Carlson, P., Francke, T., et al. 1997, *ApJ*, 487, 415
- . 2000, *ApJ*, 532, 653
- Boezio, M., Bonvicini, V., Schiavon, P., et al. 2001, *ApJ*, 561, 787
- Bronfman, L., Cohen, R. S., Alvarez, H., May, J., & Thaddeus, P. 1988, *ApJ*, 324, 248
- Cao, Z. 2010, *Chinese Physics C*, 34, 249
- Chang, J., Adams, J. H., Ahn, H. S., et al. 2008, *Nature*, 456, 362
- Consolandi, C., & on Behalf of the AMS-02 Collaboration. 2014, *ArXiv e-prints*, arXiv:1402.0467
- Cordes, J. M., Weisberg, J. M., Frail, D. A., Spangler, S. R., & Ryan, M. 1991, *Nature*, 354, 121
- Coutu, S., Beach, A. S., Beatty, J. J., et al. 2001, *International Cosmic Ray Conference*, 5, 1687
- Davis, A. J., Mewaldt, R. A., Binns, W. R., et al. 2000, 528, 421
- Derbina, V. A., Galkin, V. I., Hareyama, M., et al. 2005, *ApJ*, 628, L41
- Donato, F., Maurin, D., Brun, P., Delahaye, T., & Salati, P. 2009, *Physical Review Letters*, 102, 071301
- Donato, F., Maurin, D., Salati, P., et al. 2001, *ApJ*, 563, 172
- Duvernois, M. A., Simpson, J. A., & Thayer, M. R. 1996, *A&A*, 316, 555
- Dwyer, R. 1978, *ApJ*, 224, 691
- Engelmann, J. J., Ferrando, P., Soutoul, A., Goret, P., & Juliusson, E. 1990, *A&A*, 233, 96
- Fox, D. B., Kashiyama, K., & Mészáros, P. 2013, *ApJ*, 774, 74
- Giler, M. 1983, *Journal of Physics G Nuclear Physics*, 9, 1139
- Gordon, M. A., & Burton, W. B. 1976, *ApJ*, 208, 346
- Grygiel, C., Pautrat, A., Sheets, W. C., et al. 2008, *Journal of Physics Condensed Matter*, 20, 2205
- Guo, Y.-Q., Feng, Z.-Y., Yuan, Q., Liu, C., & Hu, H.-B. 2013, *New Journal of Physics*, 15, 013053
- Guo, Y. Q., Hu, H. B., Yuan, Q., Tian, Z., & Gao, X. J. 2014, *ApJ*, 795, 100
- Gupta, N. 2013, *Astroparticle Physics*, 48, 75
- Hooper, D., Blasi, P., & Dario Serpico, P. 2009, *J. Cosmology Astropart. Phys.*, 1, 25
- Höörandel, J. R. 2006, *Journal of Physics Conference Series*, 47, 41
- Höörandel, J. R. 2004, *Astroparticle Physics*, 21, 241
- Hu, H.-B., Yuan, Q., Wang, B., et al. 2009, *ApJ*, 700, L170
- Hunter, S. D., Bertsch, D. L., Catelli, J. R., et al. 1997, *ApJ*, 481, 205
- IceCube Collaboration. 2013, *Science*, 342, arXiv:1311.5238
- Joshi, J. C., Winter, W., & Gupta, N. 2014, *MNRAS*, 439, 3414
- Juliusson, E. 1974, *ApJ*, 191, 331
- Lukasiak, A. 1999, *International Cosmic Ray Conference*, 3, 41
- Macias, O., & Gordon, C. 2014, *Phys. Rev. D*, 89, 063515
- Maehl, R. C., Ormes, J. F., Fisher, A. J., & Hagen, F. A. 1977, *Ap&SS*, 47, 163
- Mertsch, P., & Sarkar, S. 2009, *Physical Review Letters*, 103, 081104
- Neronov, A., & Semikoz, D. 2014, *ArXiv e-prints*, arXiv:1412.1690
- Neronov, A., Semikoz, D., & Tchernin, C. 2014, *Phys. Rev. D*, 89, 103002
- Orito, S., Maeno, T., Matsunaga, H., et al. 2000, *Physical Review Letters*, 84, 1078
- Orth, C. D., Buffington, A., Smoot, G. F., & Mast, T. S. 1978, *ApJ*, 226, 1147
- Panov, A. D., Adams, J. H., Ahn, H. S., et al. 2006, *ArXiv Astrophysics e-prints*, astro-ph/0612377
- Porter, T. A., & Strong, A. W. 2005, *International Cosmic Ray Conference*, 4, 77
- Ptuskin, V. S., & Khazan, Y. M. 1981, *AZh*, 58, 959
- Razzaque, S. 2013, *Phys. Rev. D*, 88, 081302
- Said, S. S., Wolfendale, A. W., Giler, M., & Wdowczyk, J. 1981, *International Cosmic Ray Conference*, 2, 344
- Sako, T. K., Kawata, K., Ohnishi, M., et al. 2009, *Astroparticle Physics*, 32, 177
- Sanuki, T., Motoki, M., Matsumoto, H., et al. 2000, *ApJ*, 545, 1135
- Sciascio, G. D. 2014, *IJMPD*, 23, 1430019
- Seo, E. S., & Ptuskin, V. S. 1994, *ApJ*, 431, 705
- Simon, T., Linsky, J. L., & Schiffer, III, F. H. 1980, *ApJ*, 239, 911
- Stephens, S. A., & Streitmatter, R. E. 1998, *ApJ*, 505, 266
- Strong, A. W., Moskalenko, I. V., & Reimer, O. 2000, *ApJ*, 537, 763
- Su, M., Slatyer, T. R., & Finkbeiner, D. P. 2010, *ApJ*, 724, 1044
- The Fermi LAT collaboration, Ackermann, M., Ajello, M., et al. 2014, *ArXiv e-prints*, arXiv:1410.3696
- Tibaldo, L., Grenier, I. A., & for the Fermi LAT Collaboration. 2009, *ArXiv e-prints*, arXiv:0907.0312
- Gluczykont, M., Hampf, D., Einhaus, U., et al. 2012, in *American Institute of Physics Conference Series*, Vol. 1505, American Institute of Physics Conference Series, ed. F. A. Aharonian, W. Hofmann, & F. M. Rieger, 821–824
- Torii, S., Tamura, T., Tateyama, N., et al. 2001, *ApJ*, 559, 973
- Trotta, R., Jóhannesson, G., Moskalenko, I. V., et al. 2011, *ApJ*, 729, 106
- Völk, H. J., & Berezhko, E. G. 2013, *ApJ*, 777, 149
- Yin, P.-F., Yuan, Q., Liu, J., et al. 2009, *Phys. Rev. D*, 79, 023512
- Yuan, Q., Bi, X.-J., Chen, G.-M., et al. 2015, *Astroparticle Physics*, 60, 1
- Yüksel, H., Kistler, M. D., & Stanev, T. 2009, *Physical Review Letters*, 103, 051101
- Zhang, J., Bi, X.-J., Liu, J., et al. 2009, *Phys. Rev. D*, 80, 023007
- Zhang, J., Yuan, Q., & Bi, X.-J. 2010, *ApJ*, 720, 9